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LINE NARROWED LASER WITH BIDIRECTION BEAM EXPANSION

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PATENT APPLICATION

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LINE NARROWED LASER WITH BIDIRECTION BEAM EXPANSION

This invention relates to lasers and in particular to line narrowed excimer lasers. This invention is a continuation-in-part of Serial No. 09/470,724, filed December 22, 1999 and Serial No. 09/716,041, filed November 17, 2000.

BACKGROUND OF THE INVENTION

Narrow Band Gas Discharge Lasers

Gas discharge ultraviolet lasers used as light sources for integrated circuit lithography typically are line narrowed. A preferred line narrowing prior art technique is to use a diffraction grating based line narrowing unit along with an output coupler to form the laser resonant cavity. The gain medium within this cavity is produced by electrical discharges into a circulating laser gas such as krypton, fluorine and neon (for a KrF laser); argon, fluorine and neon (for an ArF laser); or fluorine and helium and/or neon (for an F_2 laser).

Prior Art Line-Narrowing Technique

A sketch of such a prior art system is shown in FIG. 1 which is extracted from Japan Patent No. 2,696,285. The system shown includes output coupler (or front mirror) 4, laser chamber 3, chamber windows 11, and a grating based line narrowing unit 7. The line narrowing unit 7 is typically provided on a lithography laser system as an easily replaceable unit and is sometimes called a “line narrowing package” or “LNP” for short. This unit includes two beam expanding prisms 27 and 29 and a grating 16 disposed in a Litrow configuration so that diffracted beam propogates right back towards the incoming beam. The output of these excimer lasers are typically rectangular with the long dimension of for example 20 mm in the vertical direction and a short dimension of for example 3 mm in the horizontal direction. Therefore, in prior art designs, the beam is typically expanded in the horizontal direction so that the FIG. 1 drawing would represent a top view.

The Grating Formula

Another prior art excimer laser system utilizing a diffraction grating for spectrum line selection is shown in FIG. 2. The cavity of the laser is created by an output coupler 4 and a grating 16, which works as a reflector and a spectral selective element. Output coupler 4 reflects a portion of the light back to the laser and transmits the other portion 6 which is the output of the laser. Prisms 8, 10 and 12 form a beam expander, which expands the beam in the horizontal direction before it illuminates the grating. A mirror 14 is used to steer the beam as it propogates towards the grating, thus controlling the horizontal angle of incidence. The laser central wavelength is normally changed (tuned) by turning very slightly that mirror 14. A gain generation is created in chamber 3.

Diffraction grating 16 provides the wavelength selection by reflecting light with different wavelengths at different angles. Because of that only those light rays which are reflected back into the laser will be amplified by the laser gain media, while all other light with different wavelengths will be lost.

The diffraction grating in this prior art laser works in a Littrow configuration, when it reflects light back into the laser. For this configuration, the incident angle $\alpha$and the wavelength λ are related through the formula:

$$2dn \sin\alpha = m\lambda \qquad (1)$$

where α is the incidence angle on the grating, m is the diffraction order, n is refractive index of gas, and d is the period of the grating.

Because microlithography exposure lenses are very sensitive to chromatic abberations of the light source, it is required that the laser produce light with very narrow spectrum line width. For example, state of the art excimer lasers are now producing spectral linewidths on the order of 0.5 pm as measured at full width at half maximum values and with 95% of the light energy concentrated in the range of about 1.5 pm. New generations of microlithography exposure tools will require even tighter spectral requirements. In addition, it is very important that the laser

central wavelength be maintained to very high accuracy as well. In practice, it is required that the central wavelength is maintained to better than 0.05 – 0.1 pm stability.

A need exists for greater narrowing of the laser beam.

SUMMARY OF THE INVENTION

The present invention provides for a grating based line narrowing unit with bi-directional beam expansion for line narrowing lasers. In a preferred embodiment a beam from the chamber of the laser is expanded in the horizontal direction with a three-prism beam expander and is expanded in the vertical direction with a single prism. A narrow band of wavelengths in the expanded beam is reflected from a grating in a Littrow configuration back via the two beam expanders into the laser chamber for amplification.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a first prior art line narrowed laser system.

FIG. 2 shows a second prior art line narrowed laser system.

FIG. 3 shows the effect on wavelengths of vertical beam deviation.

FIGS. 4A, 4B and 4C show elements of a preferred embodiment of the present invention.

FIG. 5 shows beam expansion coefficient possible with one prism.

FIG. 6 shows a helium purge arrangement.

FIGS. 7, 8 and 8A-D show LNP's equipped for fast feedback control.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Sub B1

Preferred embodiments of the present invention can be described by reference to the drawings.

In reality, formula (1) presented in the Background Section only works when all the beams incident on the grating have the same direction in the vertical axes, and this direction is normal to diffraction grating grooves. Diffraction grating grooves are placed vertically so formula (1) works for beams which lay in the horizontal plane.

Real excimer laser beams, however, have some divergence in both horizontal and vertical directions. In this case, formula (1) is modified and becomes

$$2dn \sin\alpha \cdot \cos\beta = m\lambda \qquad (2)$$

In this formula, β is the beam angle in the vertical direction, the rest of the variables are the same as in (1). In the case of β = O; i.e., when the beam has no divergence in the vertical direction, $\cos\beta = 1$ and formula (2) becomes (1).

It is important to note, that grating does not have any dispersion properties in the vertical direction, that is, its reflection angle in the vertical direction does not depend on the light wavelength, but is rather equal to the incident angle. That means, in the vertical direction the reflecting facets of the grating face are behaving like ordinary mirrors.

Beam divergence in the vertical direction has significant effect on line narrowing. According to formula (2), different vertical angles β would correspond to different Littrow wavelengths λ. FIG. 3 shows dependence of Littrow wavelength λ on the beam vertical deviation, β. Typical prior art excimer laser might have a beam divergence of up to ± 1.0 mrad (i.e., a total beam divergence of about 2 mrad). FIG. 3 shows that a portion of a beam propogating with a 1 mrad vertical tilt (in either up or down direction) will have the Littrow wavelength shifted by 0.1 pm to the short

wavelength direction for that portion of the beam. This wavelength shift leads to broadening of the whole beam spectrum. Prior art excimer lasers, having $\Delta\lambda_{FWHM}$ bandwidth of about 0.6 pm does not substantially suffer from this effect. However, as the bandwidth is reduced, this 0.1 pm shift becomes more important. New excimer laser specifications for microlithography will require bandwidth of about 0.4 pm or less. In this case, it becomes important to reduce this broadening effect.

First Preferred Embodiment

A preferred line narrowing module of the present invention is shown in FIGS. 4A, B and C. It has three beam expanding prisms that expand the beam in the horizontal direction and one additional prism, which expands the beam in the vertical direction.

FIG. 4A is a top view. FIG. 4B is a side view from the side indicated in FIG. 4A. (In FIG. 4B the prisms are depicted as rectangles representing the portion of the prisms through which the center of the beam passes.) FIG. 4C is a prospective view. Note that the grating 16 and mirror 14 are at a higher elevation than prisms 8, 10, and 12. Note that the expanded beam heads off in a direction out of the plane of the horizontal beam expansion. The beam then is redirected back into a second horizontal plane parallel to the plane of the horizontal expansion by mirror 14 onto the face of the grating 16 which is positioned in the Littrow configuration in the second horizontal plane. (Grating 16 is shown as a line in FIG. 4B representing the intersection of the horizontal center of the beam with the grating surface.)

In the preferred embodiment, each of the three horizontally expanding prisms expands the beam by about 2.92 times. Therefore, total beam expansion in the horizontal direction is $2.92^3 = 25$ times. The beam expansion in the vertical direction is 1.5 times. (The degree of expansion is exaggerated in FIG.S 4B and C.) This vertical beam expansion does not directly affect the beam divergence in the laser cavity or the vertical beam divergence of the output laser beam, but it does reduce the vertical divergence of the beam as it illuminates the grating surface. After the beam is reflected from the grating, prism 60 contracts the beam in its

vertical direction as it passes back through the prism thus increasing its divergence back to normal. This reduced divergence of the beam as it illuminates the grating results in a reduction in the wavelength shift effect thus producing better line-narrowing. A vertical tilt of 1 mrad of the beam before it goes through this prism is reduced to $\frac{1\,mrad}{1.5}$ = 0.67 mrad. According to FIG. 3, this will correspond to wavelength shift reduction from 0.1 pm to a mere 0.044 pm making this effect insignificant for line narrowing of the next generation of lasers.

Persons skilled in the art will recognize that in addition to the above-described specific embodiments of the present invention, there are many other embodiments. For example, prism 60 can be placed before prism 8, or between any two of prisms 8, 10, and 12. Prism combinations other than 3 prisms for horizontal beam expansion and 1 prism for vertical beam expansion can be used as well. Techniques for substantially real time control of several wavelength parameters are described in a United States patent application filed September 3, 1999, Serial No. 09/390,579 and in a United States patent application filed October 31, 2000, Serial No. 09/703,317 which are incorporated by reference herein. These techniques include fast feedback control of the position of the beam expanding prisms, grating curvature and tuning mirror position. Control of the position of the laser chamber is also provided. FIG. 6 shows an LNP with helium purge. FIG. 7 is a combination block diagram schematic drawing of the entire laser system and FIG. 8A and 8B are drawings of the LNP with the added feedback control features. In the FIG. 8 embodiment, the curvature of the grating is controlled by grating curvature stepper motor 30 to compensate for the distortion caused by the hot gas layer on the face of the grating. In the FIGS. 8A-D embodiment, the curvature of grating 82 is controlled with seven piezoelectric devices 86 acting through seven invar rods 84 against backing block 88 and compression spring 90. This embodiment provides very fast adjustment of the curvature of the grating face. FIG. 5 shows possible beam expansion coefficients that can be achieved with a single prism by adjusting the incident angle.

The scope of the present invention should be determined by the appended claims and their legal equivalents.